Iron and vegetarian diets

Summary

- Vegetarians who eat a varied and well balanced diet are not at any greater risk of iron deficiency anaemia than non-vegetarians.
- A diet rich in wholegrains, legumes, nuts, seeds, dried fruits, iron-fortified cereals and green leafy vegetables provides an adequate iron intake.
- Vitamin C and other organic acids enhance non-haem iron absorption, a process that is carefully regulated by the gut.
- People with low iron stores or higher physiological need for iron will tend to absorb more iron and excrete less.
- Research to date on iron absorption has not been designed to accurately measure absorption rates in typical Western vegetarians with low ferritin levels.

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Iron is an essential nutrient for haemoglobin and myoglobin formation and is vital for health and peak performance. Much of our iron requirement is met through recycling of the iron in red blood cells.[1] The amount of iron stored is carefully regulated by intestinal absorption, as we have a limited ability to excrete excess iron.[2]

Groups considered at risk of iron deficiency

There are three levels of iron deficiency, in increasing order of severity: depleted iron stores, early functional iron deficiency and iron deficiency anaemia (Box 1). Iron deficiency limits oxygen delivery to cells, resulting in weakness, fatigue, reduced immunity, shortness of breath, sensitivity to cold, and heart palpitations. Iron deficiency anaemia in pregnant women can result in premature delivery, low birthweight in infants and higher infant mortality. Other symptoms include delayed psychomotor development in infants and impaired cognitive function.[3]

Iron deficiency is the most common nutritional deficiency in the world, affecting about 25% of the global population, particularly young women and children.[4] At most risk are people who follow restricted diets. In developing countries this is usually due to a limited food supply, but in Western countries like Australia it is most commonly seen in young obese women who follow restricted energy diets to lose weight.[5]

Iron deficiency is not always caused by inadequate dietary intake, but may result from various medical conditions. Dialysis treatment in people with chronic renal failure can lead to loss of iron; gastrointestinal inflammation (eg, in Crohn's disease or coeliac disease) may impair iron absorption; and gastrointestinal blood loss (eg, associated with colorectal cancer, aspirin use or genitourinary diseases) may cause iron deficiency, particularly in older people. Excessive intake of zinc (due to zinc supplementation) may also impair iron absorption.[3]

It is commonly thought that vegetarians (people who exclude meat, poultry and seafood from their diet, but include dairy foods and/or eggs) and vegans (those who exclude all animal products) may be more prone to iron deficiency. Additional concerns about vegetarian diets include lower bioavailability of iron from plant sources (relative to animal sources) due to dietary inhibitors such as phytate in plants. In this article we consider (i) whether plant-based vegetarian diets can provide enough iron from non-meat sources to prevent iron deficiency; (ii) factors that affect how much iron we absorb; and (iii) whether the higher recommended dietary intake (RDI) of iron for vegetarians in the 2006 revised *Nutrient reference values for Australia and New Zealand including recommended dietary intake*[6] is warranted.

Types and best sources of iron

There are two types of iron in food: haem and non-haem iron. In animal products, 40% of the total iron content is haem iron and 60% non-haem iron.[7] Haem iron provides 10%–15% of total iron in meat-eating populations, but because of its higher and more uniform absorption (estimated at 15%–35%), haem iron could contribute at least 40% of all iron absorbed.[8] Plant foods contain only non-haem iron, which is found naturally in wholegrain cereals and breads; dried beans and legumes; dark green leafy vegetables; dried fruits; and nuts and seeds. Many breakfast cereals and some breads are also fortified with iron.

Even for non-vegetarians, most iron in the Australian diet comes from plant foods rather than meat. Less than 20% of iron intake comes from meat and meat products and about 40% comes from cereals and cereal products.[9] The same is true in the United Kingdom, where 45% of dietary iron comes from cereals and cereal products and less than 20% comes from meat and meat products.[10] Iron-fortified cereals make an important contribution to iron intake in both vegetarian and non-vegetarian meal plans, particularly in energy-restricted diets.[5] RDIs for iron have been set based on the assumption that a substantial

1 Three levels of iron deficiency*

There are three levels of iron deficiency commonly used to evaluate iron status:

Depleted iron stores

Depleted iron stores are indicated by a serum ferritin level of < 12–15 μg/L,† but no apparent limitation in iron supply. An increased total iron binding capacity (TIBC) indicates depletion of iron stores, but is a less precise measure than ferritin level.

- Serum ferritin concentration < 12 μg/L
- TIBC > 400 μg/dL

Early functional iron deficiency

In early functional iron deficiency, iron supply to the bone marrow and other tissues is suboptimal, but there is no decrease in haemoglobin level and therefore no anaemia.

- Transferrin saturation < 16%

Iron deficiency anaemia

In iron deficiency anaemia, there is a measurable deficit in erythrocytes, the most accessible functional compartment.

- Haemoglobin concentration < 135 g/L (male); < 115 g/L (female)
- Mean cell volume < 80 fL

* Adapted from United States Institute of Medicine Panel on Micronutrients.[3]
† < 12 μg/L in US; < 15 μg/L in Australia. ◆

amount of iron will come from non-meat sources. The iron content per 100 g of commonly available plant and animal foods is shown in Box 2. The iron content of plant sources of iron per common serve size is shown in Box 3.

Iron stores: regulation, adaptation and impact on absorption

The amount of non-haem iron absorbed is primarily determined by the body's need for iron — people with the lowest iron stores will absorb more and excrete less.[8,13] Humans can adapt successfully to a wide range of iron requirements and intakes.[14] If iron intake is low, vegetarians adapt by excreting less faecal ferritin. In pregnant women, who need the most iron, absorption can increase by 60% relative to normal.[15,16] Non-haem iron is nearly as well absorbed as haem iron by people with very low iron stores.[13] There is apparently no advantage in storing more than a minimal amount of iron.[17] RDIs for iron are set with the goal of maintaining serum ferritin levels at 15 μg/L or functional adequacy.[3]

Haem iron and non-haem iron are both absorbed in the small intestine, but via different mechanisms. Haem iron is absorbed through the gut wall intact, regardless of how much we need.[18] Non-haem iron absorption is more carefully controlled, as it is more readily absorbed when the body has need for iron — a protective measure for iron overload.[13] This sensitivity is vital, as the body has limited mechanisms for excreting excess iron: shedding skin, sloughing off of mucosal cells in the intestinal and urinary tracts, loss of hair, and menstruation.

Bioavailability of iron: inhibitors and enhancers

Non-haem iron bioavailability is influenced by various dietary components that either enhance or inhibit its absorption. The efficiency of non-haem iron absorption in people with low iron stores depends on these enhancing and inhibiting food constituents being consumed concurrently.[13] Although inhibitors and enhancers may cancel each other out, particularly in a diet that includes a wide variety of foods,[19] it is wise to be aware of their possible effects until more is known about their full impact.

The main inhibitor of non-haem iron absorption is phytate, or phytic acid, which is usually found in legumes, nuts, wholegrain cereals and unprocessed bran. Processing the wholegrain removes much of the phytate content, but also removes other beneficial nutrients such as iron and zinc. Soaking and sprouting legumes, grains and seeds reduces phytate levels, as does leavening of bread.[20] Phytic acid may actually provide health benefits as a potent antioxidant, reducing the risk of several chronic diseases, including various forms of cancer.[20-22] Other inhibitors of non-haem iron absorption include polyphenol-containing beverages such as tea (including herbal teas), coffee, cocoa and red wines.[23]

2 Iron content of commonly available plant and animal foods*

Foods	Iron per 100 g
Plant foods	
Iron-fortified breakfast cereals	4.0–16.0 mg
Pumpkin seeds/pepitas	10.0 mg
Iron-fortified bread	7.1 mg
Sundried tomatoes	5.6 mg
Sesame seeds/tahini paste	5.2 mg
Cashew nuts	5.0 mg
Mixed-grain bread roll	4.7 mg
English spinach, raw	3.5 mg
Dried apricots	3.1 mg
Tofu, firm	2.9 mg
Fortified malted chocolate beverage, with whole milk	2.7 mg
Dried dates	2.6 mg
Lentils/soybeans/kidney beans	1.8–2.2 mg
Amaranth, cooked	2.1 mg
Tofu, silken/soft	1.8 mg
Quinoa, cooked	1.5 mg
Figs, dried	1.4 mg
Baked beans	1.0 mg
Animal foods	
Liver, chicken/beef/veal	6.0–11.0 mg
Kangaroo, fillet, grilled	4.1 mg
Beef, round steak, grilled	3.3 mg
Lamb chop, grilled	2.9 mg
Beef, sirloin steak, grilled	2.2 mg
Beef, fillet, lean, grilled	2.2 mg
Egg, whole, boiled	1.6 mg
Salmon, Atlantic, grilled	1.3 mg
Pork fillets, trimmed	1.0 mg
Turkey breast, baked	0.6 mg
Chicken breast, baked	0.5 mg
Bream/flathead, grilled	0.4 mg
Cheese, cheddar	0.2 mg
Milk, whole	0.04 mg

* From Food Standards Australia New Zealand. NUTTAB 2010 online searchable database.[11] ◆

3 Plant sources of iron per common serve*

Source	Iron per serve
Amaranth grain, cooked, 1 cup	5.2 mg
Iron-fortified bread, 2 slices	4.2 mg
Lentils, dried peas or beans, cooked, 1 cup	3.8 mg
Iron-fortified breakfast cereals, average serve	1.2–3.0 mg
Tofu, firm, 1/2 cup (100 g)	2.9 mg
Quinoa, cooked, 1 cup	2.8 mg
Cashews, 25 nuts (50 g)	2.6 mg
Tempeh (fermented soybean), cooked, 100 g†	2.2 mg
Fortified yeast spread, 5 g	1.8 mg
Baked beans, 1/2 cup (140 g)	1.8 mg
Soybeans, 1/2 cup (90 g)	1.8 mg
Dried apricots, 10 halves (50 g)	1.6 mg
Rolled oats, cooked, 1 cup	1.3 mg
Fortified malted chocolate beverage, 1 tsp (5 g)	1.3 mg
Almonds, dry roasted, 20–25 nuts (30 g)	1.1 mg
Brown rice, 1 cup	1.0 mg
Wheatgerm, 1 tbsp (10 g)	1.0 mg
Broccoli, cooked, 1/2 cup (100 g)	1.0 mg

tbsp = tablespoon. tsp = teaspoon. * From Food Standards Australia New Zealand. AUSNUT 2007 online searchable database.[12] † Source: product information. ◆

While some studies have found that oxalic acid (present in spinach, silverbeet and beetroot leaves) may inhibit iron absorption, recent studies suggest that its effects are relatively insignificant.[24] Calcium has also been considered an inhibitor of both haem and non-haem iron absorption, but recent research suggests that, over a long period of time, calcium has a limited effect on iron absorption (possibly due to an adaptive physiological response).[25] Nevertheless, it may be best to avoid consuming high-calcium supplements with meals.[26]

The most significant enhancer of iron absorption is vitamin C (both synthetic and dietary), which can enhance absorption up to sixfold in those who have low iron stores,[27] overcoming the effects of phytic acid, polyphenols, calcium and milk proteins.[3,8,28,29] Absorption is increased as much as three- to sixfold with the addition of 50 mg of vitamin C per meal.[30] Vitamin C facilitates the conversion of Fe^{3+} (ferric) to Fe^{2+} (ferrous) iron, the form in which iron is best absorbed. Vegetarians typically have high intakes of vitamin C from a wide variety of fruit and vegetables. Meals rich in vitamin C may have no effect on serum ferritin levels if iron stores are already elevated.[31]

Other organic acids (citric, malic and lactic acids),[32] as well as vitamin A and β-carotene, enhance non-haem iron absorption.[33] An ascorbic acid derivative, erythorbic acid (E315), used widely as an antioxidant in processed foods, appears to be almost twice as effective as ascorbic acid in enhancing non-haem iron absorption.[34]

Meat also enhances non-haem iron absorption, but animal proteins (milk protein, egg proteins and albumin) inhibit iron absorption.[7] It was previously thought that soy protein also had an inhibitory effect on iron absorption,[35] but new research shows that iron in soy is in the form of ferritin and is highly available. It has no negative effect on iron status,[36,37] and is as well absorbed as iron from ferrous sulfate.[38]

Estimating how much iron we absorb

The amount of total iron available from a mixed diet (including meat) is estimated at 18%, whereas the amount of total (non-haem) iron available from a vegetarian diet is considered to be about 10%.[3] Estimates of iron absorption rates are based on short-term and single-meal studies (meals high in inhibitors) that are usually carried out in people with adequate iron stores. In such people, iron absorption will have been down-regulated and is unlikely to accurately reflect absorption over the long term. Single-meal studies do not allow for intestinal adaptation involving increased absorption and decreased losses.[39] For a more accurate estimate of iron absorption in vegetarian diets, studies need to be done on vegetarians (with the usual low ferritin levels) who eat more typical vegetarian diets.

Some researchers state that concerns over non-haem iron bioavailability and the effect of enhancers and inhibitors are less important than previously thought,[19,28,39,40] and that iron absorption is underestimated.[41] In fact, researchers report that iron status is more important than bioavailability in determining the amount of non-haem iron absorbed[8,13,42] and that, in women, menstrual blood loss (rather than dietary composition) is the major determinant of iron stores.[42]

4 Estimated average requirement (EAR)* and recommended dietary intake (RDI)† of iron per day, by sex and age group[6]

	Male			Female			Pregnant women			Lactating women		
Age (years)	EAR	RDI	180% of RDI	EAR	RDI	180% of RDI	EAR	RDI	180% of RDI	EAR	RDI	180% of RDI
1–3	4 mg	9 mg	16.2 mg	4 mg	9 mg	16.2 mg	—	—	—	—	—	—
4–8	4 mg	10 mg	18 mg	4 mg	10 mg	18 mg	—	—	—	—	—	—
9–13	6 mg	8 mg	14.4 mg	6 mg	8 mg	14.4 mg	—	—	—	—	—	
14–18	8 mg	11 mg	19.8 mg	8 mg	15 mg	27 mg	23 mg	27 mg	48.6 mg	7 mg	10 mg	18 mg
19–30	6 mg	8 mg	14.4 mg	8 mg	18 mg	32.4 mg	22 mg	27 mg	48.6 mg	6.5 mg	9 mg	16 mg
31–50	6 mg	8 mg	14.4 mg	8 mg	18 mg	32.4 mg	22 mg	27 mg	48.6 mg	6.5 mg	9 mg	16 mg
51–70	6 mg	8 mg	14.4 mg	5 mg	8 mg	14.4 mg	—	—	—	—	—	—
> 70	6 mg	8 mg	14.4 mg	5 mg	8 mg	14.4 mg	—	—	—	—	—	—

* The EAR is a daily nutrient level estimated to meet the requirements of half the healthy individuals of a particular sex and life stage. † The RDI is the average daily dietary intake level that is sufficient to meet the nutrient requirements of nearly all healthy individuals (97%–98%) of a particular sex and life stage. ◆

5 A sample meal plan designed to meet the iron requirements of a 19–50-year-old vegetarian woman, showing non-haem iron content of the foods*

Meal	Iron content
Breakfast	
Bowl of cereal with fruit, and poached egg on toast	
2 fortified wholegrain wheat biscuits	3.0 mg
4 strawberries	0.3 mg
10 g chia seeds	0.7 mg
1/2 cup low-fat fortified soy milk	0.7 mg
1 slice multigrain toast and 1 teaspoon olive oil spread	0.8 mg
1 poached egg	1.0 mg
Snack	
Nuts and dried fruit	
30 g cashews	1.5 mg
6 dried apricot halves	0.7 mg
Lunch	
Chickpea falafel wrap	
1 wholemeal pita flatbread	2.0 mg
1 chickpea falafel	2.9 mg
30 g hummus	0.8 mg
1/2 cup tabouli	1.6 mg
Salad	0.3 mg
Snack	
Banana and wheatgerm smoothie	
3/4 cup low-fat fortified soy milk	1.0 mg
1 teaspoon wheatgerm	0.3 mg
1 banana	0.4 mg
Dinner	
Stir-fry greens with tofu and rice	
100 g tofu	7.9 mg
2 spears asparagus, 1/3 cup bok choy and 25 g snow peas	1.3 mg
12 g cashews	0.6 mg
1 cup cooked brown rice	1.0 mg
Snack	
Fortified malted chocolate beverage	
1 cup low-fat fortified soy milk	1.3 mg
10 g fortified malted chocolate powder	2.5 mg
Total iron	**32.6 mg**

* Source: FoodWorks 2009 (incorporating Food Standards Australia New Zealand's AUSNUT [Australian Food and Nutrient Database] 1999), Xyris Software, Brisbane, Qld. ◆

Are vegetarians at risk of iron deficiency?

Vegetarian and vegan diets generally contain just as much or more iron than mixed diets containing meat.[43-45] The 2003 UK National Diet and Nutrition Survey[46] showed that a vegetarian diet was not associated with lower-than-average total iron intake[47,48] and that there was little association between indicators of iron status and dietary iron intake.[42] Compared with meat-eaters, vegetarians may often have lower serum ferritin levels (although still within the normal range), even when their iron intakes are adequate,[44,49-51] but the physiological impact of reduced ferritin levels in vegetarians is unknown at this time. Vegetarians may reduce their risk of low iron levels by eating foods rich in enhancers, such as vitamin C and organic acids.[47]

In Western countries like Australia, where we enjoy a varied food supply, vegetarians are no more likely to suffer from iron deficiency anaemia than non-vegetarians.[13] Low iron stores, without iron deficiency anaemia, have not been shown to adversely affect function.[13] Iron deficiency clearly impairs function only when haemoglobin concentrations are measurably decreased, but this has not been shown across all studies.[13,15] In the large European Prospective Investigation into Cancer and Nutrition (EPIC)-Oxford study of 43 000 women, vegetarians and non-vegetarians had similar iron intakes and haemoglobin concentrations.[44] Many studies in Western societies suggest there is little difference, if any, in iron status (measured by haemoglobin levels, haematocrit, total iron-binding capacity, transferrin saturation and serum iron levels) between vegetarians and non-vegetarians,[15,52] but a number of studies suggest that vegetarians are at greater risk of having low iron stores (as reflected by serum ferritin).[15]

Higher iron requirement for vegetarians — is it justified?

The current Australian RDI for iron is based on research by the United States/Canadian Institute of Medicine (IOM), which recommends for the first time that the iron requirement for vegetarians be 1.8 times that of the regular RDI.[6] Interestingly, the UK Food Standards Agency has not set a higher iron requirement for vegetarians.[53] Although the research is far from conclusive, the IOM's dietary reference intake committee appears to have used a single 1991 study[19] to justify the 80% greater iron requirement for vegetarians.[3] This is of questionable validity, as the study was not looking at a typical Western vegetarian diet, but rather at a diet that was specifically designed to reduce the absorption of non-haem iron and was only marginally "vegetarian", as it contained limited amounts of fruits and vegetables. One study group was given meals that were designed to maximally enhance non-haem iron absorption (meals included meat and vitamin C-rich fruits and vegetables). Another group was given meals designed to maximally inhibit non-haem iron absorption (meals excluded meat and vitamin C-rich fruits and vegetables but included foods and beverages high in inhibitors). The IOM committee based its recommended iron requirement for vegetarians on the latter group. This

same study concluded that iron bioavailability issues (enhancers and inhibitors) are less important than has been traditionally thought over the long term.[19]

Current (2006) RDIs for iron[6] are shown in Box 4. The current RDI for non-vegetarian women aged 19–50 years (18 mg/day) is slightly higher than the previous (1991) RDI (16 mg/day).[54] The current estimated average requirement (EAR) for iron for these women (ie, the daily nutrient level estimated to meet the requirements of half the healthy women in this group) of 8 mg/day, as compared with the RDI, reflects the very high variability in iron requirements among women because of significant differences in menstrual loss.[6] For premenopausal women, blood loss through menstruation is the most significant factor affecting iron status, while dietary composition appears largely unrelated to iron status.[55] A number of studies have reported an association between the length of menstrual periods and serum ferritin concentrations.[56]

The higher RDIs for pregnant women (Box 4) ensure an adequate supply of iron to the fetus and developing infant. During pregnancy, iron absorption increases from 7% at 12 weeks to 36% at 24 weeks and 59% at 36 weeks.[16] The UK Food Standards Agency has not set higher iron requirements for pregnant women, assuming that existing body iron stores (if adequate at conception) will provide what is required, given that menstruation has ceased and intestinal absorption has increased.[53]

As iron absorption is substantially greater when the body has a need, as in the case of pregnancy, it seems reasonable to assume that the bioavailability of iron from vitamin C-enhanced vegetarian meals will be considerably greater when the long-term vegetarian has an increased need for iron (as shown by a low ferritin level). Thus it is pertinent to ask whether it is really necessary to recommend a higher iron requirement for vegetarians when adaptive processes respond to lower iron stores. Future research with long-term vegetarians eating more typical vegetarian meals over a period of time (rather than examining responses relating to a single meal) would be valuable in addressing this issue.

There is a higher prevalence of iron deficiency in obese people, possibly due to inadequate iron intake or a higher blood volume. Chronic inflammation in obese people is associated with higher levels of hepcidin, which down-regulates intestinal iron absorption. Serum ferritin is not considered a good indicator of iron status in obese people, as serum ferritin levels are elevated by inflammation.[5,57]

A sample meal plan appropriate for 19–50-year-old lacto-ovo-vegetarian women, who have the highest iron requirements of any group other than pregnant vegetarian women, is shown in Box 5. The sample meal plan also meets the requirements for other key nutrients (except vitamin D and long-chain omega-3 fatty acids). For more details on meeting nutrient reference values on a vegetarian diet, as well as other sample meal plans, see the article by Reid and colleagues (*page 33*).[58]

Conclusion

Well planned vegetarian diets provide adequate amounts of non-haem iron if a wide variety of plant foods are regularly consumed. Research studies indicate that vegetarians are no more likely to have iron deficiency anaemia than non-vegetarians. Vegetarian diets are typically rich in vitamin C and other factors that facilitate non-haem iron absorption. The limited iron absorption studies conducted to date have not yet clarified how much iron Western vegetarians require daily. Research studies, which have been used to set official RDIs, have not taken into account long-term adaptive mechanisms, such as increased absorption and reduced excretion when iron stores are low, or during times of increased physiological need.

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